UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL DAMAGE INVESTIGATION OF COMPOSITE PLATES SUBJECTED TO IMPACT LOADING CONDITIONS

RISBY MOHD SOHAIMI

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EXPERIMENTAL DAMAGE INVESTIGATION OF COMPOSITE PLATES SUBJECTED TO IMPACT LOADING CONDITIONS

By

RISBY MOHD SOHAIMI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of Requirements for the Degree of Master of Science

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DEDICATION

I would not be truly thankful if I did not express gratitude towards my mum and dad who always taught me to chase the dreams: when I caught it, learn to live with it. Also I would like to fully thank them for the necessary contributions made especially during my current studies.

Above all, my deepest gratitude and love goes to my wife, Siti Noor Adnalizawati. She is my inspiration and guiding light in everything I do. The many personal sacrifices she has made for me to accomplish this work is greatly appreciated. She has been there through it all, the good and the bad. I will be eternally thankful for her understanding and support.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

EXPERIMENTAL DAMAGE INVESTIGATION OF COMPOSITE PLATES SUBJECTED TO HIGH AND LOW IMPACT LOADING CONDITIONS

By

RISBY MOHD SOHAIMI

August 2003

Chairman : Associate Professor Abdel Magid Saleem Hammuda, Ph.D.

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The use of synthetic fibers such as glass fiber and aramid fiber carbon fiber as composite reinforcement is being increasingly applied in high performance applications since they provide certain advantage of specific high strength and stiffness as compared to metallic materials. In contrast, implementation of natural fiber as reinforcement has not yet received adequate attention from the research community.

This study investigates the damage characterization and impact resistance of synthetic and natural fiber reinforced composite square plates subjected to the changes of impact loading and width over thickness (b/d) ratio of the composite. For low velocity impact, the testing was performed using Dynatup 8250 equipped with GRC 930-I Data Interpretation System on fabricated square plates with different impact energy levels and velocities. The severity of impact damage is

macroscopically and microscopically investigated. A compressed gas gun equipped with velocity measurement system was designed and fabricated in order to facilitate the high velocity impact testing experimentations.

From the results, it has been found that mechanical and impact properties of EFBC and CFC do not posses toughness and modulus as high as GRC. Although EFBC and CFC specimens exhibit total perforation to the specimens at most impact velocities, EFBC specimen with plate thickness of 8 millimetres was found to have penetration resistance at 22 Joules of impact energy level. This is due the performance of Coir as reinforcement in polymer composites is unsatisfactory and not comparable with other natural fibers due to its mechanical properties. It can also be conclude that the impact response of EFBC and CFC specimen chances significantly as the composite thickness increases.

Impact damage was found to be in the forms of matrix cracking, fiber fracture and perforation. This study results can be a valuable reference in designing of lightweight composite structure and in developing a better understanding of test methods used to characterize impact behaviours.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

EXPERIMENTASI KEROSAKAN SECARA PENYIASATAN KEATAS PLAT KOMPOSIT BERHUBUNGAN DENGAN HENTAMAN IMPAK

Oleh

RISBY MOHD SOHAIMI

Ogos 2003

Pengerusi : Profesor Madya Abdel Majid Saleem Hammuda, Ph.D.

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Penggunaan komposit bergentian sintetik telah digunakan secara meluas semenjak diperkenalkan pada awal tahun tujuh pulah-an Penggunaan gentian sintetik seperti gentian kaca, aramid dan gentian karbon sebagai tetulang komposit semakin meningkat terutama di industri aeroangkasa, ketenteraan, marin dan industri automotif Ia telah menberikan peningkatan dari segi keutamaan terhadap ciri kekuatan spesifik dan ketelusan yang tinggi jika dibandingkan dengan bahan logam Sebaliknya, implimentasi kegunaan gentian asli sebagai tetulang masih belum diberi perhatian yang sewajarnya dan masih tidak diketahui Ini adalah salah satu faktor motivasi untuk tesis ini

Tesis ini mengkaji ciri kerosakan, ketebalan dan kesan impak untuk komposit bergentian tetulang asli dan sintetik berhubungan dengan perubahan halaju impak dan nisbah lebar keatas ketebalan plat (b/d) Kerja ujikaji dilakukan dengan menggunakan Dynatup 8250 yang dilengkapi GRC 930-I Data Interpretation System dengan mengubah halaju impak yang berlainan dimana kesan kerosakan daripada impak dikaji secara makroskopik Senapang gas termampat buatan sendiri digunakan untuk mengkaji kesan henataman impak

halaju tinggi. Kerosakan yang berlaku dijangka dalam bentuk keretakan matriks, delaminasi, dan tahap penembusan.

Keputusan telah menunjukkan bahawa cirri-ciri mekanikal dan hentaman impak bagi EFBC (komposit bergentian sawit) dan CFC (komposit bergentian kelapa) tidak mempunyai modulus dan kekuatan yang tinggi berbanding dengan GRC (komposit bergentian kaca). Walaubagaimanapun, EFBC dan CFC menunjukkan tahap penembusan keseluruhan pada kebanyakkan kelajuan impak, sample 8 milimeter EFBC telah didapati mempunyai tahap rintangan penembusan yang baik pada tahap hentaman impak 22 Joules. Tahap kegunaan Coir (sabut kelapa) sebagai tetulang dalam komposit berpolimer tidak memberangsangkan mungkin kerana ia mempunyai ciri-ciri mekanikal yang rendah berbanding dengan gentian asli yang lain. Kesimpulan daripada ujikaji ini menunjukkan respon terhadap kesan hentaman impak EFBC dan CFC berubah dengan peningkatan ketebalan. Kesimpulan yang didapati ini akan memberikan rujukan yang penting bagi rekabentuk komposit bergentian ringan bagi kegunaan aplikasi struktur dan bahan.

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I certify that an Examination Committee met on 28th August 2003 to conduct the final examination of Risby bin Mohd Sohaimi on his Master of Science thesis entitled "Experimental Damage Investigation of Composite Plates Subjected to Impact Loading Conditions" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981 The Committee recommends that the candidate be awarded the relevant degree Members of the Examination Committee are as follows

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Master of Science The members of the Supervisory Committee are as follows

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

RISBY BIN MOHD SOHAIMI

Date: 28th August 2003

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LIST OF ABBREVATIONS

CFC	Coir Fiber Reinforced Composite
EFBC	Empty Fruit Bunch Reinforced Composite
GRC	Glass Fiber Reinforced Composite
E_p	Propagation Energy
E,	Initiation Energy
Mpa	Mega Pascal
V_f	Fiber Volume Fraction
kN	Kilo Newton
MLP	Maximum load point
TP	Total point
GPa	GigaPascal
MPa	MegaPascal

CHAPTHER ONE

INTRODUCTION

The work presented in this thesis focuses on the effects of width over thickness ratio (b/d) and different type of materials on the failure mechanism, failure mode and energy absorption during an impact event. This work is also carried out in order to study the damage characterization and impact resistance of Coir-Epoxy (CFC), Oil Palm Empty Fruit Bunch-Epoxy (EFBC) and Glass-Epoxy (GRC) reinforced composite square plates subjected to the changes of impact loadings by using low and high velocity testing methods. Low velocity testing will be conducted using Dynatup 8250 instrumented impact machine, whereas for high velocity impact testing, a compressed gas gun with velocity measurement system was designed and fabricated to facilitate this experimental work. Quasi-static tests were performed in order to determine the mechanical properties of the fabricated composite plates.

Since their introduction, composite materials have been applied to a variety of structural applications. Among the most performing is graphite or carbon fiber composite, which possess one of the highest specific moduli among synthetic fiber materials (Cantwell and Morton, 1989; Dorey et al., 1998). The specific strength and stiffness of graphite epoxy composites are significantly greater thạn monolithic materials such as steel and aluminum, which make them attractive for numerous weight critical applications. Unfortunately, composites of this type have relatively poor mechanisms for absorbing energy due to local impact damage where loading is normal to the fiber plane. This is primarily due to the low strain to failure and low transverse shear strength of the graphite fiber and the brittle nature of the epoxy matrix (Zhou, 1998b).

Impact events can be categorized into four velocity ranges; low, high, ballistic, and hypervelocity. Low velocity impact may include situations such as a dropped tool (< 31 m/s) whereas high velocity impact might include a bird colliding with an airplane (31 - 240 m/s). Ballistic impact events include situations such as a projectile fired from a gun at speeds in excess of 240 m/s. Finally, orbital debris traveling in outer-space at velocities up to 15,240 m/s are considered to be hypervelocity impact events (Stilp and Hohler, 1990). Since the early 1970's,researchers have been looking for methods to improve impact properties of graphite composites such as fiber and matrix toughening, interface toughening, through-the thickness reinforcements, and hybridizing (Jacob et al., 2002).

For high-performance materials, carbon or aramid-polyamides fibers such as Kevlar are the fibers of choice. They are very strong and highly heat-resistant, so they can be used in applications where conditions are fierce, in aircraft such as the Euro Fighter 2000 for example (Robson et al., 1993). But they also tend to be expensive, so for more general applications the workhorse fiber for composite materials is glass (Gayer and Schuh, 1996; Robson et al., 1993).

Glass fibers have many benefits. They are cheap, strong and relatively easy to manufacture. But there are disadvantages too. They are very abrasive, which makes them dangerous to work with and increases wear in machines used to cut products made from composites. More importantly, glass fibers could present a health risk to those working with them. Like asbestos fibers, they are very small and once breathed in can lodge in the lungs and be absorbed into the body, which is very hazardous (Bolton, 1994; Nickel et al., 1998).

But the biggest problem with glass and other synthetic fibers is how to dispose them at the end of their lifetimes. Glass fiber reinforced composite is not biodegradable and cannot be burned because the fibers are left behind as clinker, a nasty residue, which can ruin a furnace. Nor are glass fibers easy to recycle. They break easily during the rough and tumble of reprocessing (Gayer and Schuh, 1996).

This is where natural fibers can be introduced as a substitute material. They are abundant, renewable, cheap and low density and most interesting is that it is biodegradable. Even if they are burned at the end of their lives, rather than left to biodegrade, natural fibers have an environmental advantage. Natural fibers such as coir, jute, flax, kenaf and sisal, have been used for thousands of years to make paper, textiles, cordage and other products essential to societal development. Natural fiber reinforced composites or bio-composite are gaining acceptance from manufacturing industry especially the automotive and building industry building because they can be made stronger and cheaper than with traditional plastic and glass fiber (Ellison and McNaught, 2000).

These "green" composite materials turn fibers from plants into lightweight, strong and stiff materials through innovative research (Ellison and McNaught, 2000; Gassan and Bledzki, 1999; Robson et al., 1993). Biocomposite materials have several advantages and since they are renewable based, biocomposite would reduce dependency on petroleum, which is the source for synthetic fibers production. The cost for composite materials can be reduced with large-scale usage. Potential harmful effects related to materials processing and disposal could be eliminated due to their potential biodegradability (Bolton, 1994; Gassan and Bledzki, 1999).

Since there is growing need in military and civil applications for composite materials that not only possess good structural characteristics, but good penetration resistance and greater strength during impact are being profoundly studied by researchers (Mahfuz et al., 1998; Ramakrishna et al., 1995; Zhou, 1998a).

Problem Statement

Many engineering structures that used synthetic fibers as reinforcement are subjected to impact loads or collision during service that may compromise the structural integrity of the composite and will lead to failure. It is thus important for the composite material to maintain some structural integrity until the end of the service life and prevent catastrophic failure (Soares and Sutherland, 1999).

According to Jacob et al (2002), the ability to absorb impact energy and survive is termed as "crashworthiness" structure. Where as for high velocity collision, penetration resistance is much concerned. There is an important different between crashworthiness and penetration resistance. Crashworthiness is concerned with energy absorption of energy through controlled failure mechanisms and modes that enable the maintenance of a gradual decrease in the load profile during absorption. However penetration resistance is associated with the total absorption without allowing the projectile or fragment penetration to occur during the impact event (Beaumont et al., 1974).

Therefore now natural fibers are predicted to be a positive alternative for their artificial counterparts in impact related applications Unlike relatively simple synthetic fibers, natural fibers are much more complicated. They are made up of bundles of cellulose microfibrils, thin strands of cellulose, which are wound together and surrounded by layers of hemi-cellulose and lignin (Li et al., 2000). This built-in microstructure means natural fibers can absorb a lot of energy, so that weight for weight, they are may be as strong as glass ones. But, they are much less dense. So if panels made of natural fibers are to be as strong as those made of synthetic fibers, they have to be thicker (Gassan and Bledzki, 1999). This is one of major setbacks faced by natural fiber composite but can be rectified if extensive research in impact analysis are done in order to have a better understanding of the natural fiber engineering potentials and finding out ways of improving the resistance in natural fiber reinforced materials. Therefore in this study the parameter of width over thickness (b/d) ratio is introduce to examine the effect subjected to changes in the test specimen dimensions.

Importance of the Study

Impact resistance is one of the most important properties for a part designer to consider, and without question the most difficult to quantify (Jacob et al., 2002). The impact resistance of a component is, in many applications, is a critical measure of service life. More importantly these days, it involves the perplexing problem of product safety and liability (Richardson and Wiseheart, 1996). In standard testing, such as tensile and flexural testing, the material absorbs energy slowly. In real life, materials often absorb applied forces very quickly: falling objects, blows, collisions, drops, etc. A product is more likely to fail when it is subjected to an impact blow, in comparison to the same force being applied more slowly. The purpose of impact testing is to simulate these conditions (Jacob et al., 2002; Sjoblom et al., 1988; Tai et al., 1998; Zhou and Davies, 1995).

Studies have shown that reinforcements of composite materials with natural fibers have various advantages which similar to its synthetic counterparts such as high specific strength and stiffness (Gassan and Bledzki, 1999). Local resources such as natural fibers (Coir and oil palm fibers) can be widely exploited and used to diversify its potentials in high performance composite application. (Abdul Khalil et al., 2001; Rozman et al., 1996; Rozman et al., 2000). Therefore, a more comprehensive study of the behaviour and characterization of natural fiber reinforced composite subjected to impact and penetration condition is needed to evaluate its limitations

Objectives

This present research is to study the impact resistance potential of natural and synthetic fiber reinforced composite, which may produce significant result that would improve the utilization of natural fiber into a viable materials for industry The objectives can be summarised as follows

- To design and fabricate a compressed gas gun for high velocity impact testing

- To determine the mechanical properties of natural fiber reinforced composite rectangular stripe (oil palm empty fruit bunch and coir) from tensile and flexural testing

- To examine the impact resistance, penetration behaviour and effect of width over thickness (b/d) ratio of natural fiber reinforced composite square plates (oil palm empty fruit bunch and coir) and synthetic fiber reinforced square plates (glass fiber) from low and high velocity testing Epoxy resin square plates also will be tested in low velocity condition as control specimen

- To investigate damage characteristics of natural fibers and glass fiber reinforced composite subjected to low and high impact loading

Layout of the Thesis

This thesis is primarily divided into six chapters. Following this chapter, Chapter two present a review of literature, which related the previous work done in composite impact investigations using low velocity testing and development of high velocity testing using gas gun. Explanations of natural fiber and its composite are also discussed in this chapter.

Chapter three discusses the justification of the materials and methods of this research. A detail description of a custom-made compressed gas gun (pneumatic) is presented in Chapter four and is followed by the overall experimental works done for this research in chapter five. Detail results and discussions of the work done throughout the project are being presented in this chapter. Finally, the conclusion and recommendations are presented in Chapter six followed by publications of this thesis.